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# COMMAND PROCESSORS

*by D. E. Jamison*

*Goddard Space Flight Center*
*Greenbelt, Md.*

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## ABSTRACT

Satellite activities and functions are controlled by transmission of commands from the earth. These commands are recorded at the time they are transmitted so they can be correlated with changes in satellite data when processing is performed. The command decoders discussed in this paper process the standard commands used by GSFC for satellite control. The systems were developed for real time as well as post-operative processing of command data.

CONTENTS

# COMMAND PROCESSORS

by
D. E. Jamison
*Goddard Space Flight Center*

## I. INTRODUCTION

Ground control of satellites is an important aspect of today's space programs. All the major satellites in orbit and those being developed have, or will have, the capability of responding to instructions sent from the earth. They can be instructed to change their rotational axis, to alter power distribution, to turn on and turn off experiments on board the satellite, and to transmit data to earth. Satellites as early as the Vanguard series had basic command reception capabilities. Current satellites, by virtue of their increased payload and the complex experiments they are equipped to perform, require elaborate command systems; these must distinguish between the satellites orbiting the earth, command them to perform various sequences, or call for corrections of different spacecraft subsystems when critical situations arise. The ability to control satellites by transmitted commands adds to their versatility and enables them to have a longer, and more productive data-collection lifetime. Experimental results can be examined over a longer time; scientists can call for specific experiments at prearranged intervals. The power sources servicing the satellite can be regulated to conserve energy when the transmission of experimental data is not required.

Command Centers have been established at Goddard Space Flight Center for the different satellite projects. These centers schedule and control the commands issued from ground stations. Under their control, a satellite may be referenced several times a day, or, in the event of system emergencies, referenced rapidly during short intervals.

The switching of experiments in a satellite affects the continuity of the telemetry data. Since processing these data is based upon knowledge of how they are structured, i.e., commutated during transmission, it is necessary to account for all times at which experiments have been activated by commands sent to the satellite. In order to identify such times, a standard format is generated by time encoders, and recorded along with telemetry data and commands whenever a field station tracks the satellite.

When data processing is performed, the recorded commands are correlated with the time and satellite data, in order to identify different experiments and satellite conditions. As a result, telemetry data can be edited and decommutated, and changes can be ascertained.

Satellite command decoding for data processing is a relatively new field of endeavor at Goddard Space Flight Center. The implementation of the decoding devices and subsequent data processing of all command information for the GSFC scientific satellites is handled by the Information Processing Division of the Center.

This paper is a discussion of the equipment that is used to perform this command processing.

## II. COMMAND DECODING

Three command decoders have been designed and developed by the Data Processing Branch of the Information Processing Division of Goddard Space Flight Center. These systems process commands used to control the OGO, POGO, OSO, AE-B, and BIOS satellites, as well as commands for other satellites that use command structures specified by Goddard Space Flight Center standards. Each system is built differently. The varying design criteria of the systems were based on the command formats used and on data-processing requirements. At present, three standard formats are in use: the Tone Command Standard, the Tone-Digital Command Standard, and the Pulse Code Modulation (PCM) Command Standard. They are briefly reviewed below.

Tone commands consist of discrete frequency bursts that first address a satellite and then command it to execute an operation. Address tones are unique for any individual satellite; execute tones are the same for all satellites employing the standard tone command format. Tone-digital commands are pulse-duration-modulated signals that represent binary-coded words. A command is composed of from two to five words; a satellite must recognize, out of this command, one valid combination of address and execute words in order to respond. PCM commands are the most elaborate of the three types. They consist of two frequencies that are keyed on and off to construct a binary configuration. Another, modulating frequency is used for data synchronization. The PCM command word structure is composed of synchronization, address, and command data.

The first command processor was built to process PCM and tone commands for OGO satellites. It can decode commands while satellite data are being processed on an associated telemetry data-reduction system. The output of the command processor consists of printouts of commands and NASA standard time. A second system was constructed to process tone commands for the AE-B satellite and tone-digital commands for the OSO satellite. A future processing requirement of the system will be to decode tone-digital commands for the BIOS series of satellites. The system output consists of command, time, and identification data written on magnetic tape for use by computers for command and data comparison. The third system was developed to process PCM commands for OGO satellites, and tone commands for any satellite using the standard tone-command format. The system can be adapted for simultaneous processing with a telemetry data reduction system and can also be used for real-time processing. Its output is from a card punch or a printer and consists of commands, NASA standard time, and necessary identification data.

## III. GODDARD SPACE FLIGHT CENTER COMMAND FORMATS

Command standards have been established by Goddard Space Flight Center for three types of command formats. They are the Tone Command Standard, the Tone-Digital Command Standard, and the Pulse Code Modulation (PCM) Command Standard. The command processing systems to be discussed in this article have been developed to process commands adhering to these standards. The three types of commands are being used or will be used for ground control on nearly 80 satellites from 18 different projects.

### Tone Commands

The predominant command format used is that of the tone command. It is the primary command source for most satellites and is also used in a secondary backup capacity and for emergency commanding with other satellites. The tone commands are used for situations where only a few commands are required. A command encoder at a field station generates a series of discrete tone bursts (Figure 1) which are detected by a decoder in a satellite. Once the command is decoded, a specified function is performed in the spacecraft.

A tone command consists of an address tone (which is always the same for a given satellite) and one, two, or three execute tones in sequence with it. An address tone signals the satellite decoder to arm itself; then the execute tones initiate the required function. Tone bursts can be from 0.5 seconds in duration, in increments of 0.5 second, up to 3.5 seconds. The duration is constant for each command sequence. The interval between the tone bursts in a command sequence is 0.5 seconds. At the present time, 22 discrete frequencies have been assigned, 14 as address tones and 8 as execute tones. The execute tones may be used in any order of permutation. The audio frequency range from which the tones have been designated is from 1 to 7 kHz.


Figure 1—Tone command format.

### PCM Instruction Command System

The Pulse Code Modulation (PCM) Instruction, because of its large command repertoire, is used when control over many spacecraft activities is needed. The PCM command signal (Figure 2) is frequency-shift-keyed to change the bit-weight coding. It is frequency-modulated by switching between two specified frequencies in a 7- to 9-kHz band. A bit-synchronization signal, used for bit-rate timing, is 50-percent amplitude-modulated onto the subcarrier frequencies which represent a binary one or a binary zero.

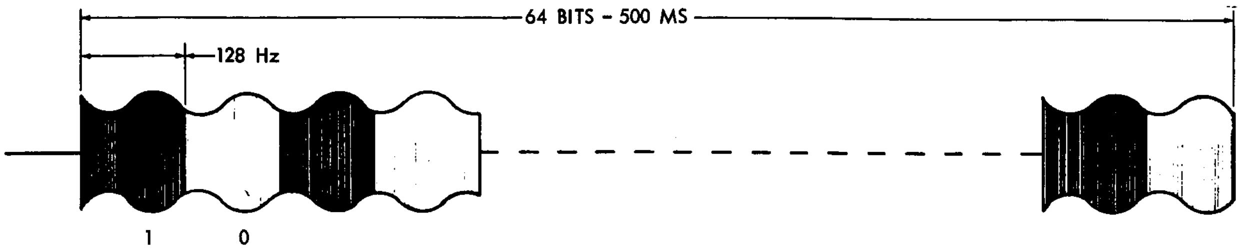



Figure 2—PCM command format.

The word length of a PCM command is 64 bits, with a maximum of 46 command-data bits and a minimum of 18 synchronization bits. When less than 46 bits are used for command data, the unused bits are considered as synchronization bits. The bit rate of current commands is 128 bits per second. A minimum of 13 zero bits precede a command word to initiate bit synchronization, followed by a single one bit to indicate that a command word field is commencing. Inside the word length of 64 bits is the command word field, which is variable in length and can be located from the 15th to the 60th bit positions. The remaining positions contain the synchronization bits. An example of this is the OGO command format. It uses bits 15 through 30 as the command word field, with the upper eight bits used as an address and the remaining eight bits used for the command function. The commands can be assigned from an octal numbering range of 000 to 377, which gives the PCM command system 256 different commands.

## Tone-Digital Commands

The Tone-Digital Command System is used by satellites with approximately 70 functions to be performed. It was developed primarily for simple, real-time, turn-on, and turn-off commands for satellites.

Tone-digital commands are pulse-duration-modulated (PDM) signals (Figure 3). The commands consist of a series of five words, each one composed of a synchronization period followed

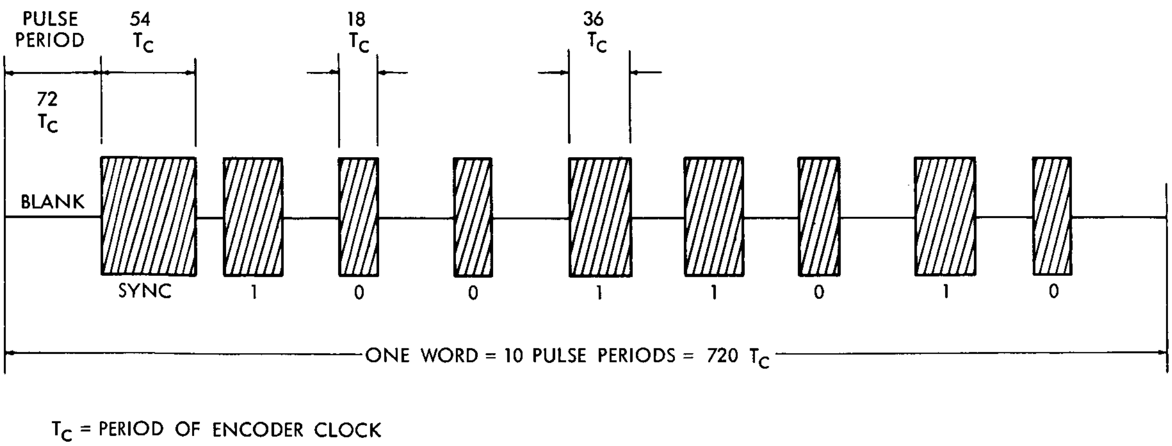



Figure 3—Tone–digital command format.

by eight bits of binary information and a blank period. The series contains a unique address word, transmitted twice, and an execute word, transmitted three times. The redundancy feature decreases the possibility of losing the commands through noise interference during transmission. A satellite will respond to any combination of one valid address word and one valid execute word in a series.

A pulse period, from which all timing is referenced, is made up of 72 cycles of a designated subcarrier frequency. The frequency can be one of eight standard tones between 7 and 11.024 kHz. Each satellite utilizing the tone-digital command system is assigned a permanent frequency. The durations of the pulse states are 100-percent off for a blank, 75-percent on for a synchronization period, 50-percent on for a binary one, and 25-percent on for a binary zero. These percentages are with respect to the pulse period defined as 72 cycles of the subcarrier frequency. The eight-bit, constant-ratio, digital-command code is in the hexadecimal radix of numbers 0 through 15. An address word consists of either six one bits and two zero bits, or two one bits and six zero bits. The execute word is comprised of four one bits and four zero bits.

In order to avoid unanticipated signals and spurious commands, a synchronization pulse must be detected, to enable the satellite to decode address words and execute words; a word must be read within a specified time frame or the satellite will not respond.

## IV. NASA STANDARD TIME CODES AND DECODING

Two types of time codes are used by NASA to establish the time (both in calendar units and in the time of day) at which information is received from a satellite or when commands are sent to it. This time information is recorded on a magnetic tape, along with telemetry data and commands which are recorded at the same time on other tape tracks. The NASA standard time codes are named the Binary Coded Decimal (BCD) time code and the Serial Decimal (SD) time code.

### BCD Time Code

The BCD time format is a 12-character word which covers time increments from hundreds of days down to units of milliseconds and includes four bits of station data for identification purposes. The BCD time, generated by time encoders at the NASA field tracking stations, actually consists of nine characters from hundreds of days and descends to units of seconds. A millisecond count is generated and added to the time word by the time-decoding equipment when the magnetic tapes are processed. Resolution of the BCD time code is to units of milliseconds. The time-code signal has the following structure: each bit of a four-bit binary-coded decimal character is determined by the number of cycles of a 1-kHz carrier frequency and the occurrence of an increase in carrier signal strength. A binary one is represented by six cycles of the carrier with a three-to-one amplitude increase of the signal. A binary zero is represented by two cycles of the carrier frequency with a corresponding increase in amplitude. The encoded BCD time-code signal is shown in the lower portion of Figure 4.

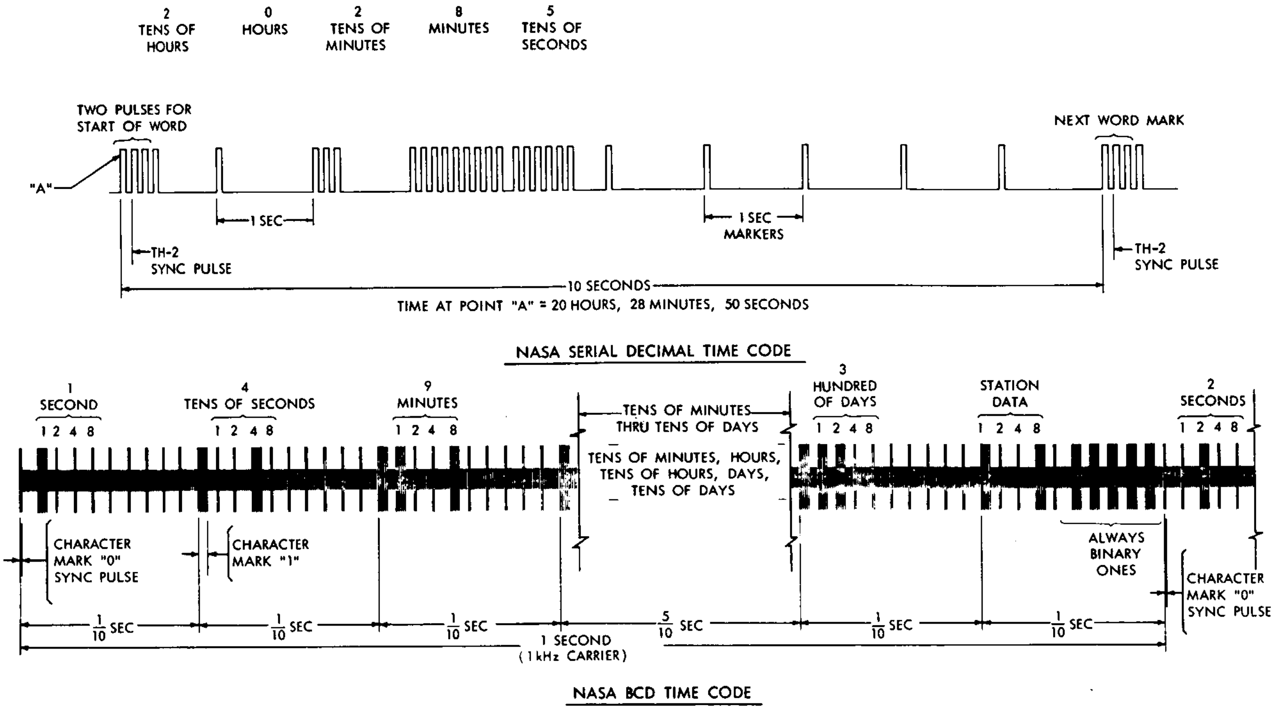



Figure 4—BCD and SD time codes.

## Serial Decimal Time Code

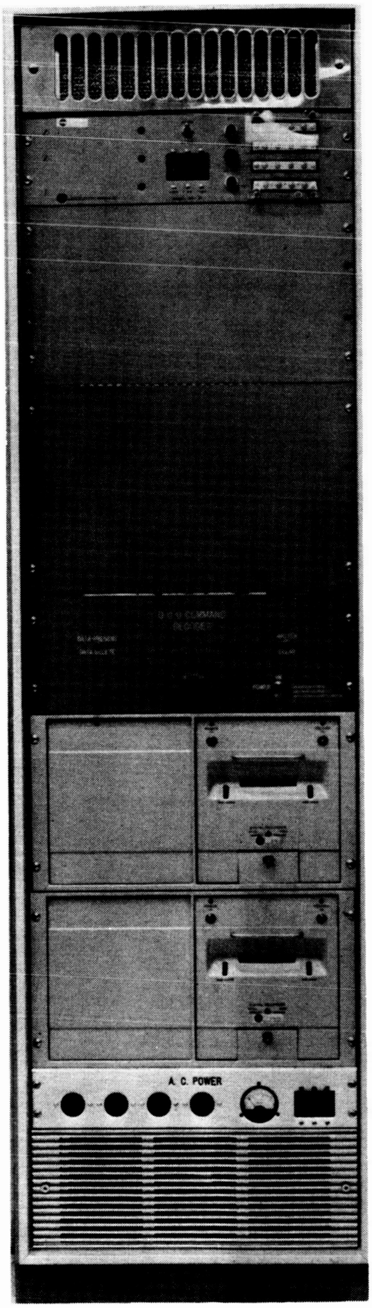
The SD time code (upper portion of Figure 4) encoded and recorded at the field stations consists of five time characters. They are tens of hours, units of hours, tens of minutes, units of minutes, and tens of seconds. Serial Decimal time has a resolution to one second, but this can be improved to one millisecond by using a linearizing frequency that is recorded at the same time. The linearizing is derived from the oscillator that develops the time-code frequency pulses.

## Time Decoding

The time decoders incorporated in the command processor systems have various methods of decoding and processing the time codes. They all place a stored time word in an output register from which it can be extracted when requested. Readouts of time are made after any millisecond preceding the time. This requirement is placed upon the system because command data is processed randomly and a time word must be ready for extraction at all times. A time reading is requested from the time decoders and is read into the time-storage area of the command processors every time a command is processed. Time decoding is further discussed under "OGO Command Decoder System" below.

# V. OGO COMMAND DECODER SYSTEM

The OGO Command Decoder System consists of an analog magnetic tape reproducer to insert commands and NASA standard time, the OGO command decoder (Figure 5) and a STARS time



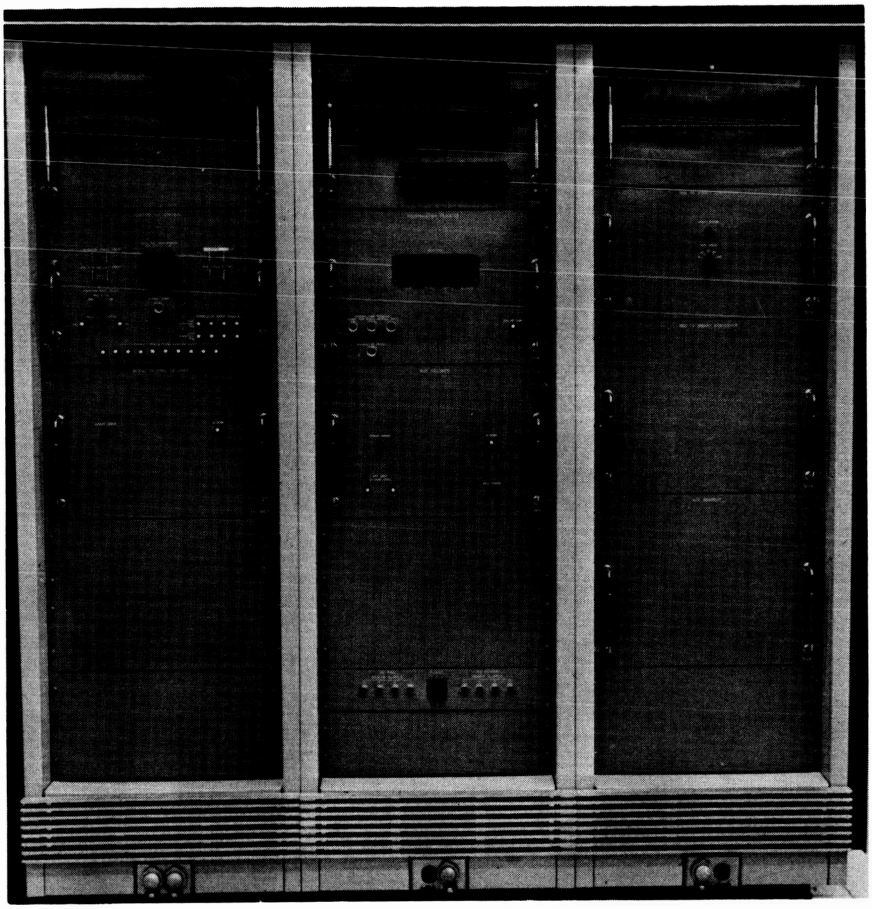



Figure 6—STARS time decoder.

decoder (Figure 6) to process the input signals, and two data-logging printers to produce an output of six BCD command characters and nine BCD time characters. The time decoder is shared with a STARS, Phase I processor, so that telemetry data processing and command processing can be performed simultaneously.

The first command decoder was developed to process the two command formats assigned to the OGO satellites; it thereby derives its name, the "OGO Command Decoder." The PCM and tone-command formats are used to instruct the satellite, and the decoder circuits handle specific types of commands within these formats.

Figure 5—OGO command decoder.

Since the OGO Command Decoder System was developed specifically for the OGO satellite command format, its circuits detect and process PCM commands with binary-number states represented by an 8.0-kHz frequency for a logical zero and an 8.6-kHz frequency for a logical one. These binary representations are frequency-shift-keyed at a 128-Hz rate to obtain bit synchronization. Sixty-four bits sent for each PCM command contain 16 relevant bits that are extracted during OGO command decoding operations. Eight of these bits represent an address of a particular satellite;

the other eight bits represent the specific command to be executed. The number range for both segments of the word is between 000 and 377 in octal notation. The command decoder recognizes the PCM command sequence, isolates the 16 bits of pertinent information, and stores the sequence in an output holding register.

The tone commands consist of three discrete frequency bursts of one-half-second duration, with one-half-second blanked intervals separating them. The tone frequency bursts employed to instruct the satellite are 1097 Hz for an address tone, and two frequencies selected from 2270, 2650, 3305, and 3850 Hz, for two execute tones. The frequencies are isolated during decoding by using a character-selection matrix which produces octal numbers corresponding to the five different tone bursts. Three translated characters are stored together in a holding register and then presented for output in an octal number representation.

The PCM command format was designated by Goddard Space Flight Center as the primary command source for the OGO satellites; and the tone commands were designated for emergency backup, or secondary commanding. Since either type of command can be recorded on the same tape, the decoder system was designed to recognize either type of format and to process it. The decoding circuits share a common input, and depend on narrow-bandpass filters to detect and separate the different frequencies of the two command formats. Once filtering takes place, the selected signal is conditioned and converted from an analog to a digital voltage representation by appropriate circuits. The converter circuits were designed and developed with operational amplifiers having the advantages of versatility and high-gain characteristics. These amplifiers are used in the analog conversion circuits for active filtering, amplification, signal inversion, pulse shaping, envelope development, and threshold detection.

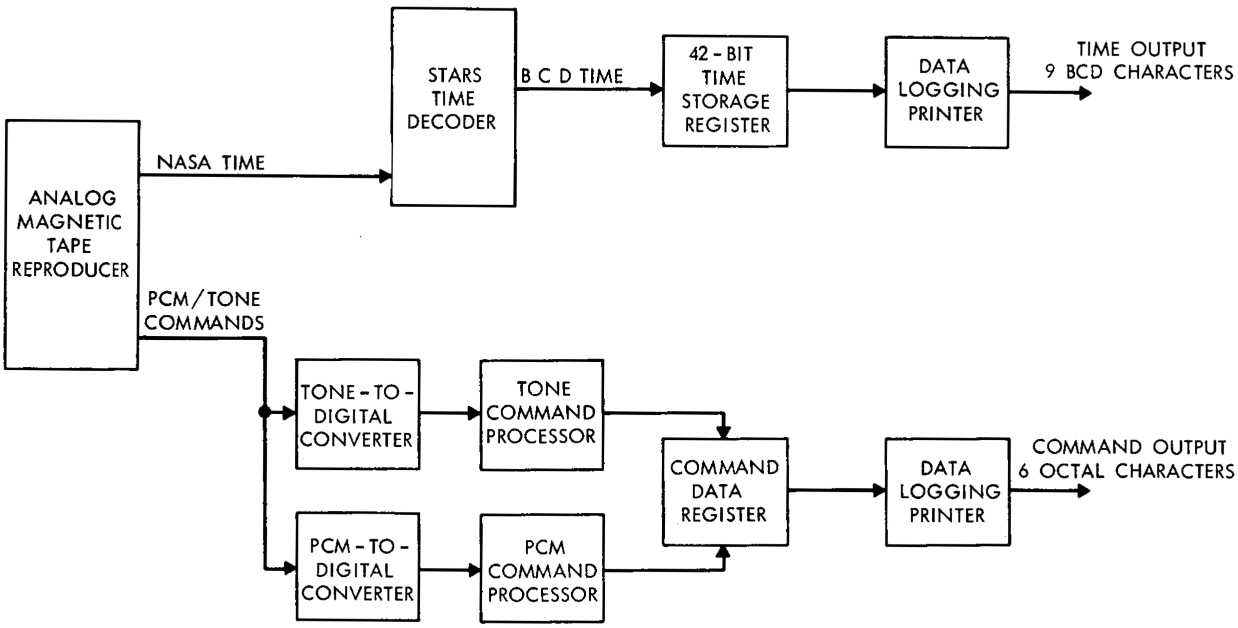



Figure 7—OGO command decoder system simplified flow diagram.

The basic configuration for the OGO Command Decoder System is shown in Figure 7. When the PCM or tone commands are reproduced on the analog magnetic tape drives, a previously recorded NASA standard time word is played back. At the instant that a command has been processed and is ready to be sent to the output printer, a signal is sent to the time-storage circuits to bring forth a time word for output to another printer. The command and time words are then printed out together.

## Functional Description of PCM Command Decoding

A block diagram of the circuit subsystems of the OGO command decoder is shown in Figure 8. The functional logic of the PCM command decoder is shown in the bottom portion.

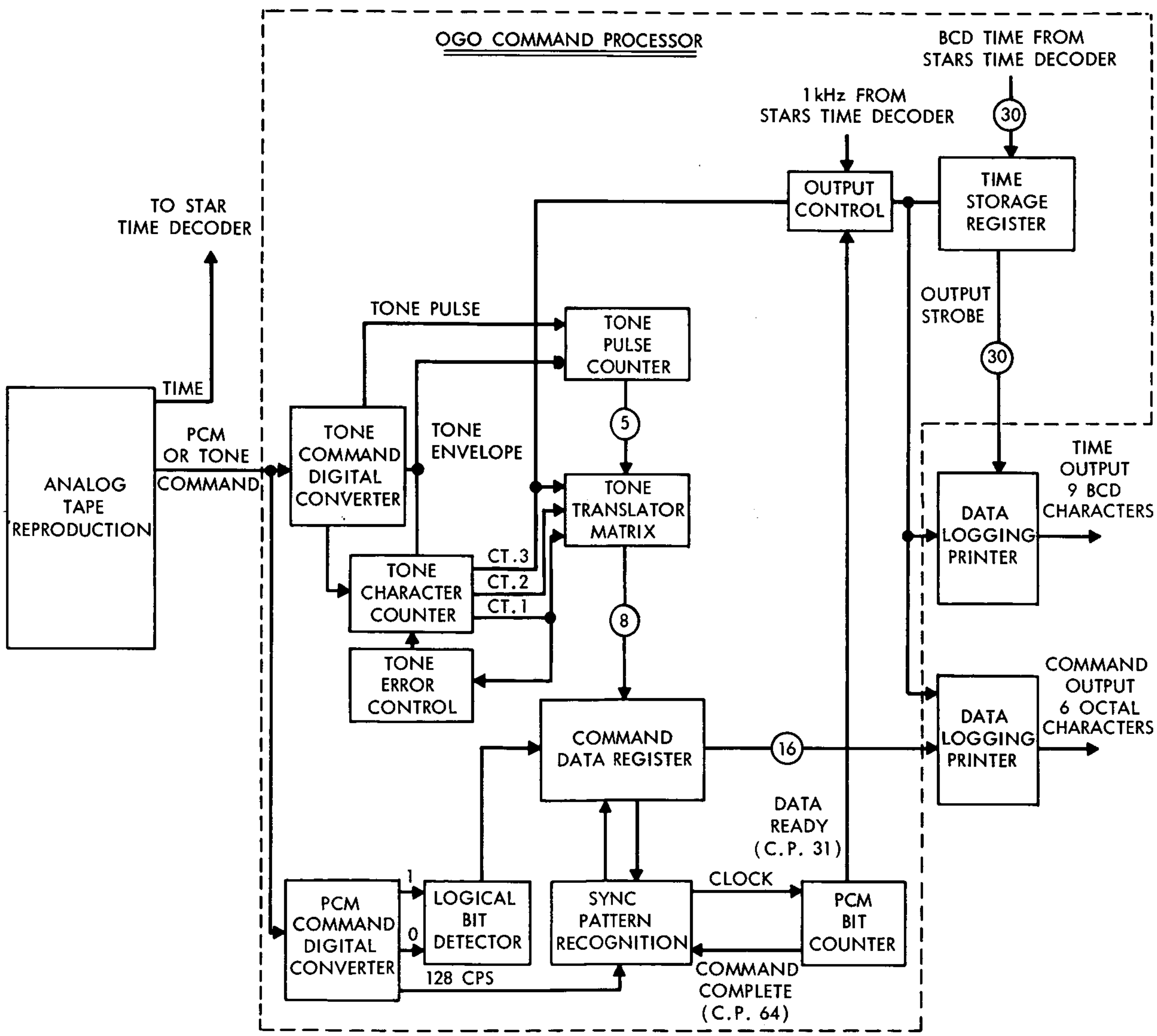



Figure 8—OGO command decoder block diagram.

The reproduced command from the analog tape drive goes to a PCM command converter and to a tone command converter. The input stage of the converters are selective bandpass filters. The filter in the PCM converter passes frequencies assigned to the PCM format for the OGO satellite, and attenuates frequencies outside of the band. The same is true of the filter in the tone converter. This ensures that PCM commands will activate only those circuits used for decoding PCM commands. (Likewise, the tone-command circuits ignore PCM commands and are activated only when a tone command frequency is received.)

The PCM decoder circuits consist of the PCM command digital converter, the logical bit detector, synchronization pattern recognition, and a PCM bit counter. The output command data register is shared with the tone command processing circuits for output storage.

The PCM command digital converter performs analog-to-digital voltage conversion, and demodulates the 128-Hz modulating signal to produce a clock pulse for the digital logic circuits. Filtering is performed to eliminate noise and tone frequencies, and the remaining signal is fed to an operational amplifier for amplitude restoration. The 8.0-kHz frequency is detected when a binary zero is sent and a voltage level representing a logical zero is produced. The 8.6-kHz frequency is detected when a binary one is sent and a voltage level representing a logical one is produced. The 128-Hz modulating envelope is extracted and shaped so that it can be used for a clock pulse.

The logical bit detector determines the reference level of the incoming data and establishes the bit polarity, i.e., voltage level, that is placed at the initial stage of the command data register so that it can be shifted in for data storage. Bits are detected and stored serially, bit by bit, as they are converted and sent to the digital logic circuits.

The sync pattern recognition circuits determine a synchronization pattern which, in turn, is used to identify a valid command word. This enables control functions to be performed that allow a count to be taken for the required bits in a command word.

The PCM bit counter is used to count the bits in a command word. After the desired count is reached, this logic locks out further pulses sent to the command storage register; this is in order to retain the 16 relevant bits extracted for the command word. At the conclusion of a decoding sequence, the counter circuitry issues a signal for an output cycle to commence.

The command data register is a common output storage for both PCM and tone commands. When it is used in conjunction with the PCM command decoder circuits, it functions as a shift register; the binary data is serially loaded into it by the 128-Hz clock pulse. When the command is unloaded, all the bits are read into the printer circuits in parallel.

## Functional Description of Tone Command Decoding

The functional logic of the tone command decoder is shown in the top portion of Figure 8. The logic is composed of the tone command digital converter, the tone character counter, the tone pulse counter, the tone translator matrix, and the tone error control.

The tone command digital converter performs three functions: (1) it filters out frequencies and noise outside of the tone command frequency band, (2) it amplifies and shapes the tone frequency pulses to a voltage level compatible with the digital logic circuits, and (3) it develops an envelope at the desired logic level used to validate the duration of a tone burst. The tone pulse counter consists of a 12-stage counter with a maximum count of 2048. It accumulates a count of the frequency pulses in each tone burst that occurs during a tone command sequence. The tone character counter records the number of tone bursts in a command sequence. It determines where a translated character, representing a particular tone frequency, is located in the command storage sequence. It also sends the control pulse to initiate an output cycle. The tone translator matrix distinguishes between the address-, execute-, and erroneous-tone frequency counts. It assigns a discrete integer to each tone burst. Each time a burst occurs, the character selected by the tone translator matrix is transferred to a designated location in the output command data register. Upon signal dropout, or the failure of special filtering networks (designed to eliminate a discrete low-frequency tone burst sent to indicate command completion*), the tone error control clears the system storage elements and resets all binary control elements to their initial conditions.

The command data register, as stated previously, is shared as a common parallel output medium by the PCM and tone command decoder networks. The translated tone command characters are placed in it by a parallel data deposit when each frequency burst has been terminated. After the final character has been stored, an output cycle is initiated.

### STARS Time Decoder

The Satellite Telemetry Automatic Reduction System time decoder processes and presents NASA standard time to the command decoder in BCD format. The decoder sets up a time word at millisecond intervals and notifies the command decoder that information is being held for a readout.

The time storage register accepts nine BCD characters from the STARS time decoder, after a command has been processed. The register momentarily holds the time word, consisting of days of the year down to units of seconds and, when strobed for an output, presents the characters in parallel to an output printer.

### Output Control

When a command sequence has been terminated, the output control circuits are alerted by a signal from either the PCM or tone command decoder circuits. The output control circuits then enable a time word to be extracted from the STARS time decoder, and temporarily store it in the time-storage register of the command processor subsystem. An output control pulse is then initiated to send both command and time to the output printers.

*This tone burst is sent only when a command is transmitted via microwave link from Goddard Space Flight Center to a NASA field station at Rosman, North Carolina, from where it is directed to the satellite. The frequency is 800 Hz and terminates command transmission.

## Output Data Logging Printers

Two line printers, operating simultaneously, print out 15 BCD characters at a time. Six characters constitute the command data and nine constitute the NASA standard time word. The printers have a printing speed of 5 lines per second.

## VI. TONE AND TONE-DIGITAL COMMAND PROCESSOR SYSTEM

The Tone and Tone-Digital Command Processor System (Figure 9) was designed and developed to decode and process the commands for the AE-B, OSO, and BIO satellites. It is constructed with variable electronic filters which enable it to process tone commands of any frequency specified within the NASA command standards. With minor signal level and timing adjustments, it can process any tone-digital command format that conforms to the command standards. The processor is part of a system (Figure 10) which consists of an analog tape reproducer, the tone and tone-digital command decoder, NASA standard-time decoder, a format control buffer, and a digital magnetic-tape recorder unit.

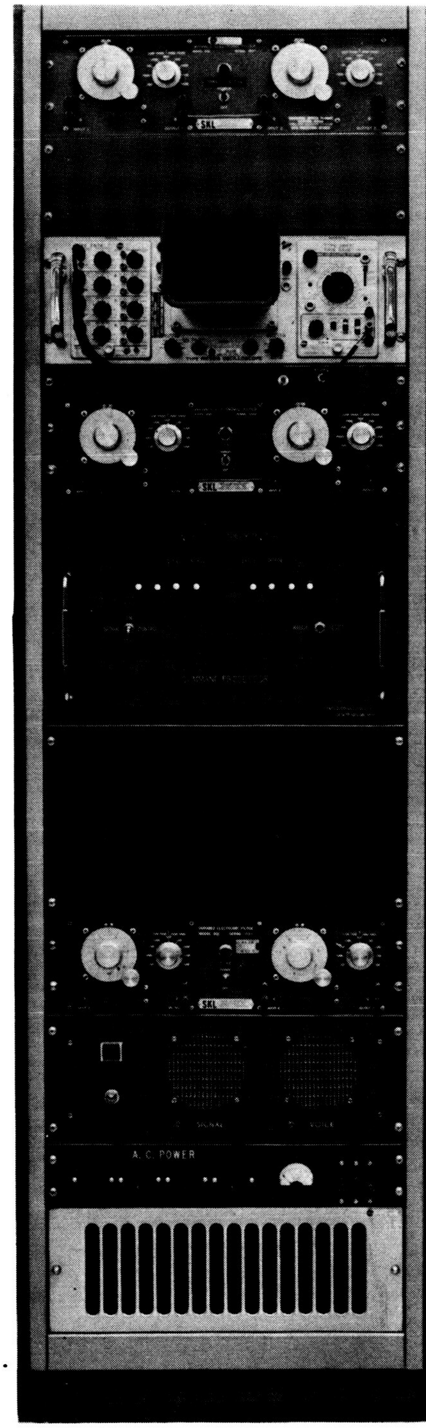



Figure 9—Tone and tone-digital command processor.

The processing circuits for the two types of command are switched on separately. The satellites for which the system was developed use only one format. That is, AE-B uses the tone command format, and the OSO* and BIOS satellites use the tone-digital commands. Separate input stages are selected, because the different command formats are never mixed together during command transmission as is the possibility for the OGO satellites. A simplified block diagram of the system is shown in Figure 11.

Command data is played back from the analog magnetic-tape reproducer to the selected command decoder. At the same time, NASA standard time is played back from another channel of the reproducer and is sent to the time decoder. The commands are decoded and temporarily held while control circuits communicate with the output circuits; then the time and command information is sent through multiplexing

*The OSO-A satellite is an exception and uses the tone command format instead of the tone-digital command format.

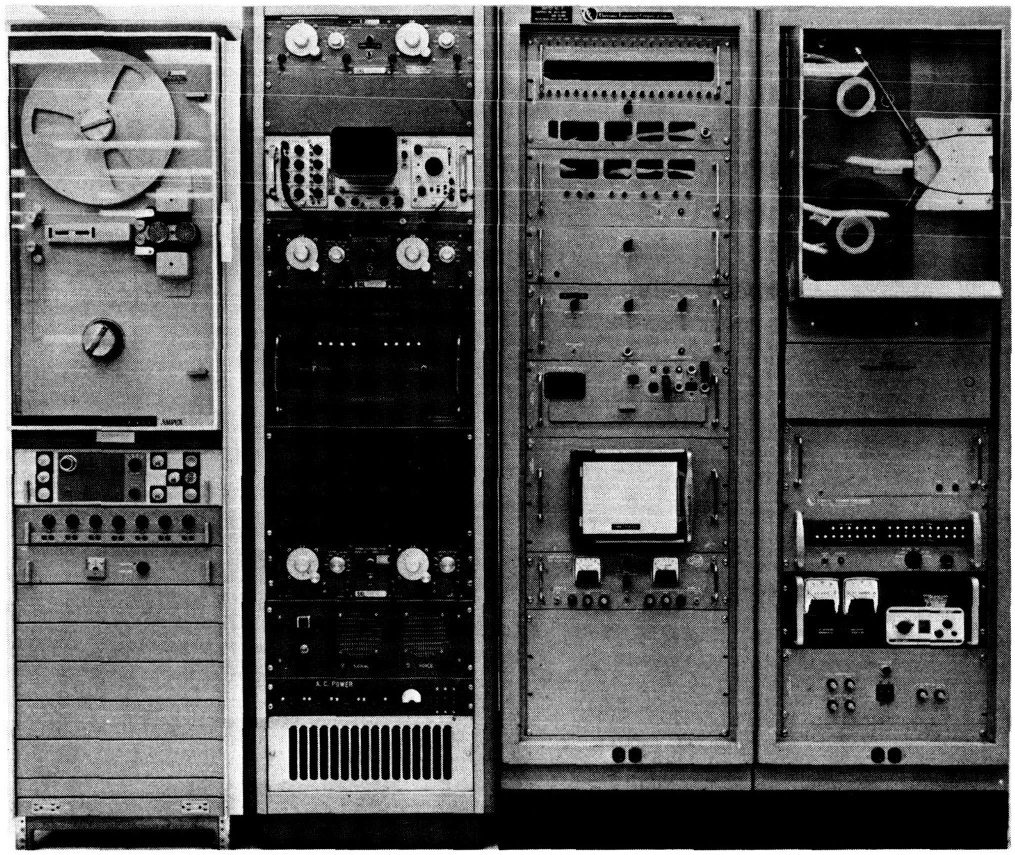


Figure 10—Command processing system.

and buffering elements to the digital tape drive, where the data are placed on magnetic tape as BCD characters.

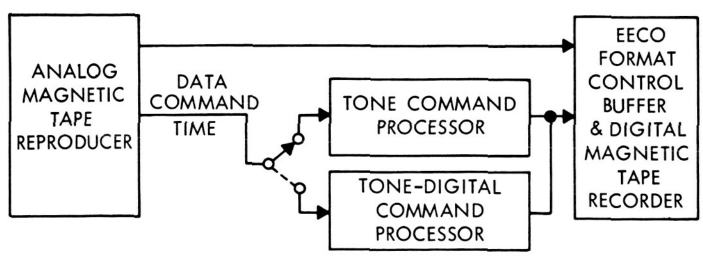



Figure 11—Tone and tone-digital command processor system flow diagram.

Command data are played from an analog tape reproducer to whichever command processor is selected. Simultaneously, NASA BCD time is played back from another track of the reproducer directly to a time decoder. A command is decoded, temporarily held while an output signal is sent to a format control buffer, and then forwarded along with a time word to the buffer where it is multiplexed, character by character, and recorded on digital magnetic tape.

## Functional Description of Tone Command Processing

The tone command processor will decode incoming commands at normal and at 4 times the recorded speed. The processor, whose subcircuits are shown diagramatically in Figure 12, is divided into the functional parts described on the next page.

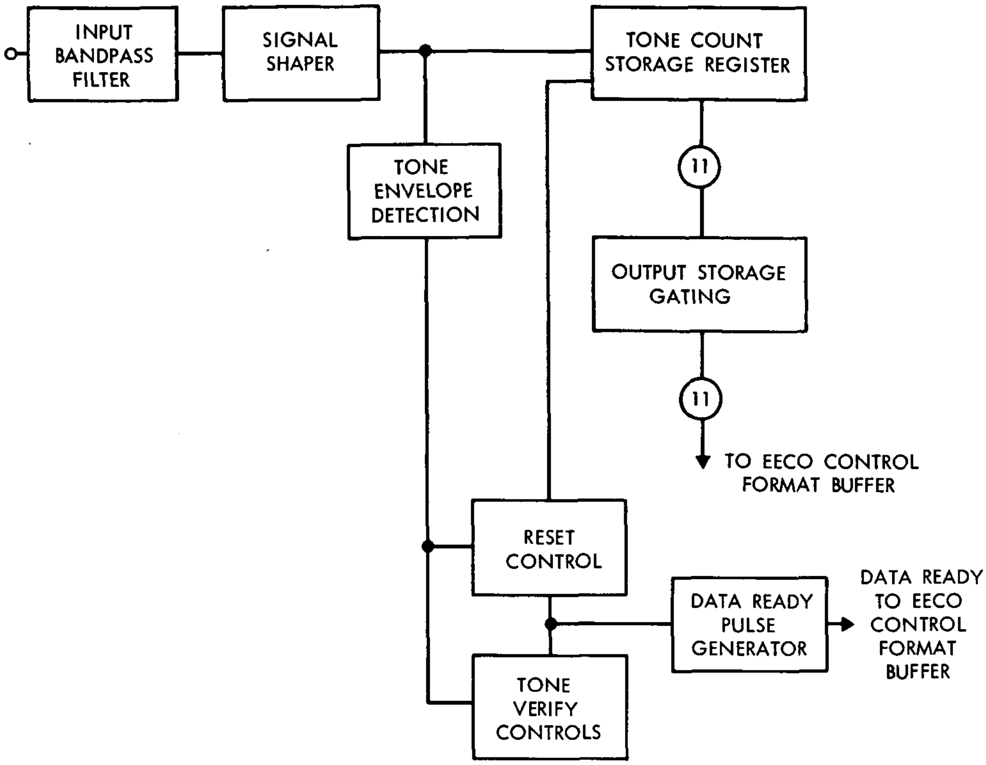



Figure 12—Tone command processor subsystem block diagram.

Signals reproduced by the analog magnetic tape drive are sent to the input bandpass filter, which rejects all frequencies below 1 kHz and above 4 kHz. The filtering thereby eliminates all frequencies outside of the range for the appropriate command frequencies. The lower and upper band edges previously quoted are multiplied by 4 when a quadrupled processing speed is selected.

The signal shaper circuit is composed of an operational amplifier and a schmitt trigger. These two elements provide low-level signal amplification, noise immunity, wave shaping, and the required voltage levels for the digital logic of the decoder.

The method of data recovery for the tone commands in this system is to count the pulses within a frequency burst, allowing for a percentage deviation from the exact count. In order to do this, an integrate and count technique is used. The tone envelope detector develops an integrated envelope over the duration of a frequency burst by following the peak signal level of the incoming tone burst. The envelope produced is used to activate a counter and to maintain control circuits for the duration of the burst. It also contributes a "flywheel" effect to prevent signal dropout and amplitude falloff.

The tone count storage register is an eleven-stage counter which accumulates a number corresponding to the total frequency pulses in a tone burst. The quantity accumulated will be the binary equivalent of the pulse count occurring over the one-half-second interval of the tone command frequency burst. When the burst is completed, the counter will contain a maximum octal count of 3777. This is equal to 2047 in decimal notation. Since the frequencies range from 1447 Hz to 3850 Hz for the OSO command format, the highest decimal count will be 1925, which is the highest correct recorded count for a tone burst of 0.5-second duration.

The output storage gating serves as a protective stage between the output of the tone command processor and the format control buffer. The gates isolate the system from electrical failures in the externally connected buffer. The gates are single-output inverters connected to the tone count storage register; they provide the drive current for the data transfer lines to the format control buffer inputs.

The tone-verify controls check the validity of a frequency burst by a duration check. Signal integration is performed on the tone envelope for 80 percent of the burst time; after this, a tone burst is considered legitimate. When a frequency burst is ascertained, the tone-verify controls initiate the sequence that sends a data-ready pulse to the control buffer and initiates a system-reset pulse after the command data have been transferred to the format control buffer.

The output of the data-ready pulse generator is a data-ready signal which initiates a loading cycle in the format control buffer. When the signal is developed, the digital command data stored in the output storage register is read into the format control buffer for character multiplexing, to be recorded on digital magnetic tape.

The reset control clears the tone-count storage register when a tone frequency burst is completed, and whenever a false or short command burst is detected. Error detection circuits in the reset control protect the system from any reset whenever the tone-verify controls establish that the criterion for a valid frequency burst of 80 percent has been met.

### Functional Description of Tone-Digital Command Processing

The tone-digital command processor (Figure 13) will decode commands at normal speed and at 4 times the speed of the original recorded information. It is constructed to process tone-digital commands, with a basic carrier cycle of 7 kHz for the OSO satellite commands, and can be adjusted or expanded to handle any frequency within the 7- to 11.024-kHz band specified by Goddard Space Flight Center for tone-digital commands. There are ten general subsections to the processor. The design concept is one calling for pulse-duration sampling and validity testing with the subsequent digital functions of clocking, shifting, error checking, and data transfer. The subsection parts are presented in the following discussion.

The input (bandpass) filter is variable and is adjustable for normal and 4 times playback speed of the analog tape. Sideband frequencies are normally placed at plus or minus 500 Hz. This is an empirical value and can be tightened if so desired. The filter attenuates all unwanted frequencies, and peaks, graphically speaking, for the specific frequency used to produce the tone-digital command-pulse timing period.

The signal from the bandpass filter goes to a pulse shaper which provides noise immunity and squares the pulses before sending them to an envelope detector, which develops an envelope over

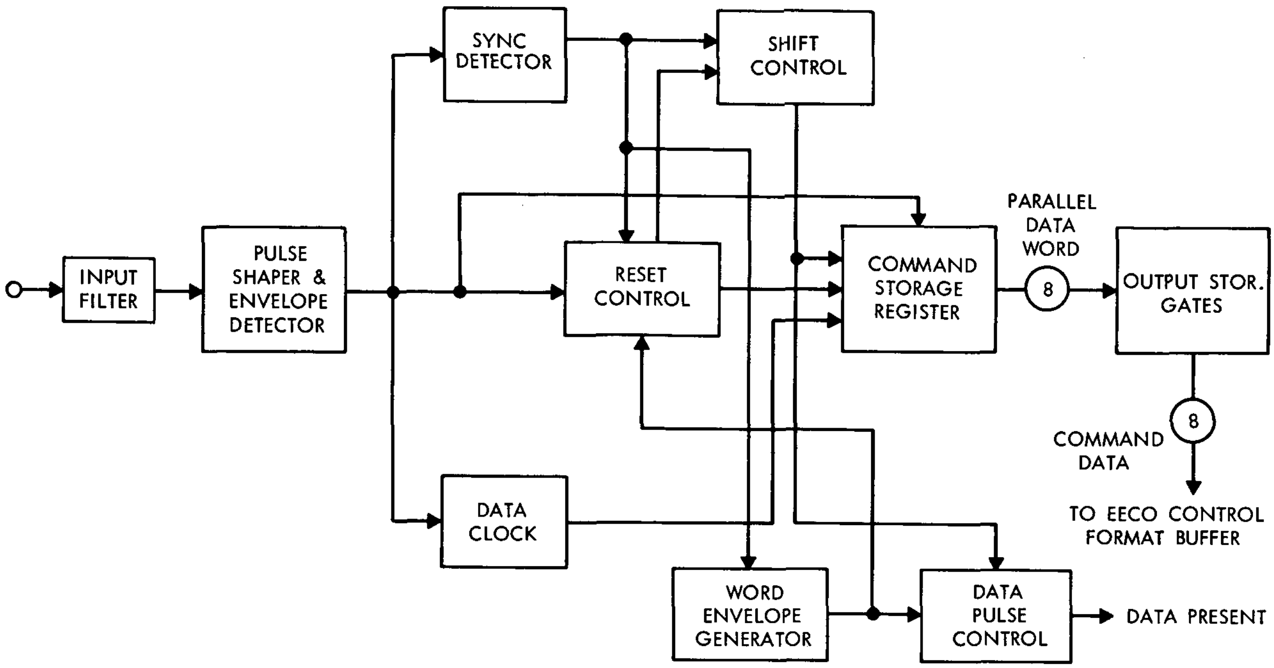



Figure 13—Tone-digital command processor subsystem block diagram.

the period of time when a frequency burst is present. The output is used for command synchronization, for developing a data clock at the bit rate of the incoming signal, for binary data determination, and for reset control.

The data clock is generated from the subcarrier frequency sent from the envelope detector. The clock delays the leading edge of the bit pulse for a time duration of 27 Tc, where Tc is defined as the period of one pulse of the carrier frequency, e.g., 0.143 milliseconds for the OSO and BIO satellites. The clock pulse is sent to the command storage register to shift in command data. Since the period of 27 Tc is midway between the 36 frequency pulses used to signify a binary one (36 Tc) and 18 frequency pulses used to signify a binary zero (18 Tc), the clock pulse probes for a difference in logical voltage levels and shifts the data bit accordingly.

The sync detector circuit consists of an integrator and a threshold detector arrangement which charges up and turns on when the sync burst preceding a tone-digital command data bit configuration appears. The sync burst lasts for 75 percent of the defined pulse period for the command format, that is, for 54 Tc. When the sync detector circuit acknowledges the receipt of a sync pulse, a command processing cycle commences. The output from the sync detector is used by the shift control circuits, for reset control in conjunction with the bit envelope developed in the envelope detector circuits and used for initiating the generation of a word-length envelope.

The shift control provides the control to the input of the command storage register. When the shift control is alerted to the presence of a command word, it provides an enable signal, allowing the data clock pulses to shift the binary bits into the storage register. The shift control also returns the output level of the data-ready signal generator to its initial logical voltage state.

The command storage register is the memory unit of the command processor. Binary data are serially shifted, bit by bit, into the register; this consists of eight flip-flop stages (the amount necessary to receive and retain a tone-digital command word). Its output is eight bits in parallel.

The output storage gates are used for single-ended outputs to provide amplification and isolation to the circuits connecting the processor interface to the control format buffer subsystem.

The word envelope generator develops a "window" that lasts for the lengths of a tone-digital command word. The trailing edge of the pulse is significant in that it represents the delayed response to the signal sent from the sync detector to the word envelope generator when a valid command sync pulse is recognized. The output is sent to the data pulse control and to the reset control circuits.

The data pulse control is a gated power amplifier that develops the "data ready" pulse to the format control buffer to notify it to record a time and command word.

The reset control circuits reset the shift control at the end of a command word output. They also reset the shift control plus all other binary elements of the command storage register when a command dropout occurs and when a command sequence (which will be from two to five command words) has been completed.

The command output circuits from the command processors are connected by a selection switch to the format control buffer. Eleven bits, representing four octal characters, are read out for each frequency burst of a tone command sequence, and eight bits, representing two hexadecimal counts, are read out for the tone-digital commands. The command characters are multiplexed into the buffer's storage area along with 12 time characters and an identification word preset into the format control buffer. The output is extracted when the last character in a command processing cycle has been stored and written onto digital magnetic tape.

### Format Control Buffer

The format control buffer is a self-contained special-purpose processing device that contains a NASA standard time decoder, a patchable multiplexer unit, a sequentially interlaced magnetic core memory, and a digital magnetic-tape recorder. Its purpose as a functional part of the Tone and Tone-Digital Command Processor System is to decode the incoming time, accept digitized data, and write the data on magnetic tape. The recorded information is later used for command correlation which is performed by high-speed digital computers.

## VII. PCM AND TONE COMMAND PROCESSOR SYSTEM

The third command processor, the PCM and Tone Command Processor (Figure 14), although developed for a particular series of satellites, was built for adaptability. It contains the best features of the previous systems as well as improved circuits brought about through experience. The system processes PCM commands for the OGO satellites and can be modified to process any

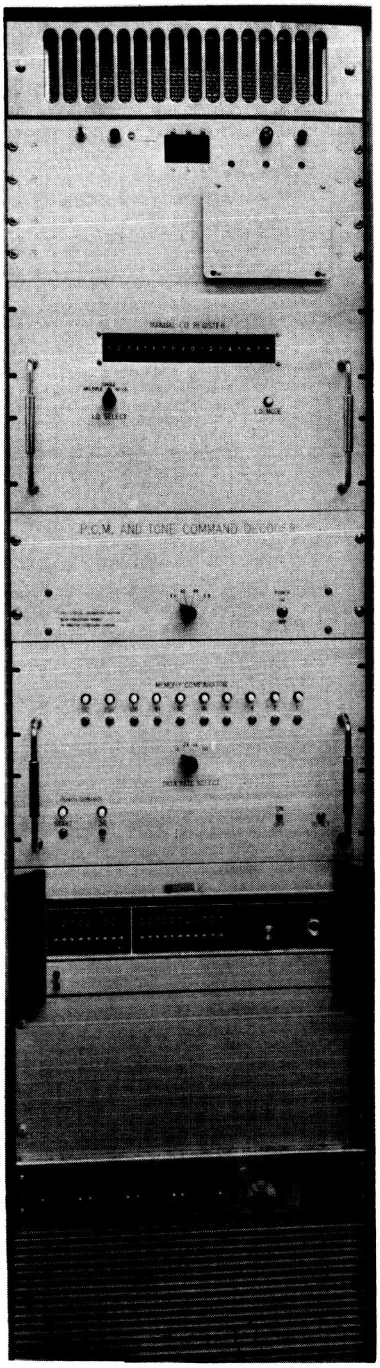


Figure 14—PCM and tone command processor.

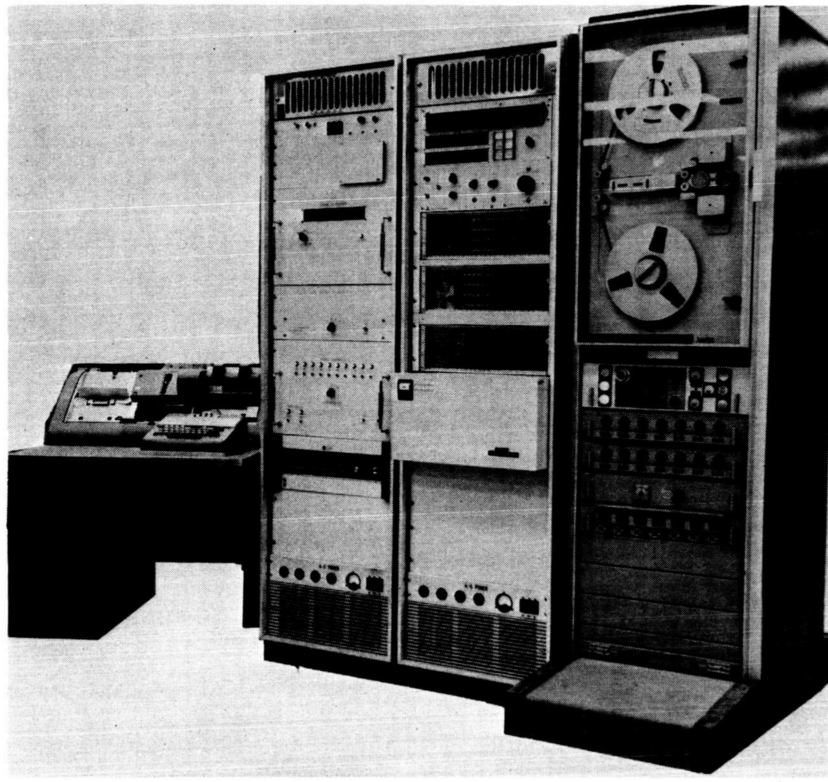


Figure 15—PCM and tone command processor system.

PCM command formats by adding supplementary filters when new subcarrier frequencies are used. The format for tone commands can be processed at any standard frequency by the tone command decoder.

The PCM and tone command processor system (Figure 15) has a magnetic analog tape input. A real-time command link can also be connected to it. A time decoder built to handle any NASA standard time codes provides the time conversion for the system. Decoded and processed commands are stored along with time and identification data in a magnetic core memory of 1024 eight-bit words. When a command processing run is terminated, the contents of the core storage can be read by calling for an output. A flow diagram for the main subsystems is shown in Figure 16.

The system processes the same formats as the OGO Command Processor System. The analog-to-digital conversion circuits employ similar operational-amplifier centered networks to condition the incoming command signals. The circuits perform at lower signal-to-noise ratios, supply greater noise rejection, and respond more rapidly to frequencies in the desired PCM and tone command ranges.

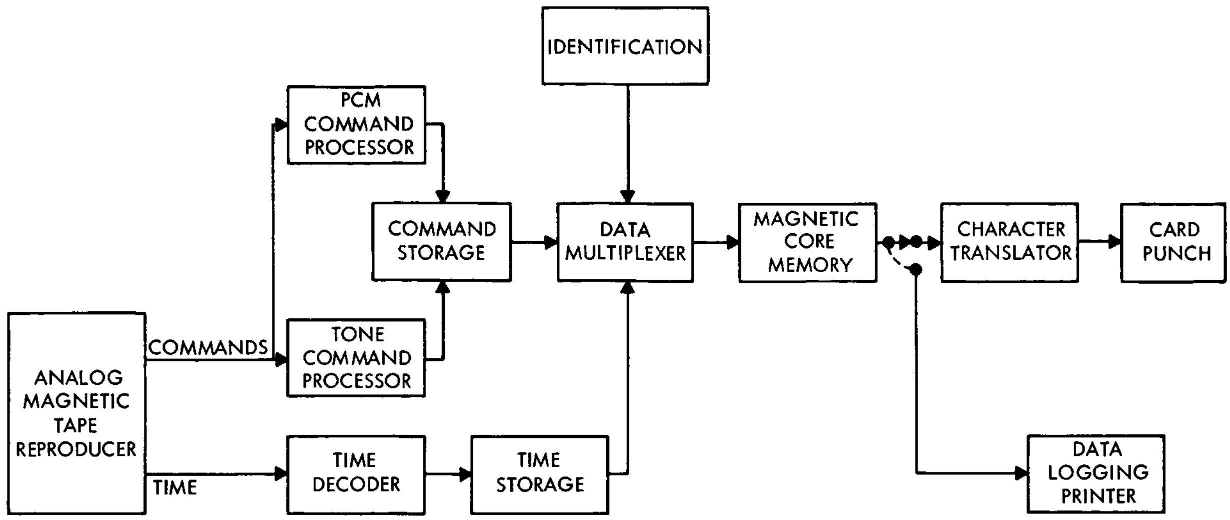



Figure 16—PCM and tone command processor system flow diagram.

The digital logic is far more extensive than in the previous system in that error-checking and signal-dropout-detection circuits, as well as appropriate control and flagging-logic circuits, are provided; thus, more significant analysis of the output data can be made.

The system operates with separate input and output cycles. The commands are processed and stored during a loading cycle. Retention of information is permanent, with the data held in non-destructive magnetic core memory units until new characters are legitimately written to replace those stored. An output cycle commences by manually starting an unload sequence. The data in memory is read out and punched and printed on tabulating cards, or printed serially, character by character, by a data-logging printer.

## Input Cycle Logic Elements

The PCM and Tone Command Processor's main logical elements are shown in Figure 17. The logic used during an input cycle consists of the following major functional components (see upper portion of figure):

1. A command decoder portion; this, in its turn, consists of: (a) a digital converter which distinguishes between incoming signal levels and performs analog-to-digital conversion of PCM and tone command formats, (b) the tone command and PCM command digital logic circuits, and (c) a commonly shared data register which holds 6 command characters.
2. A time hold register which contains circuits to accept and temporarily store 12 characters of time and to control functions carried on prior to transfer of a time word in the external time decoder.
3. An identification (ID) hold register, which contains 18 characters of identifying data connected with the information recorded on magnetic tape (the characters can be manually preset or sent from a satellite telemetry reduction system).

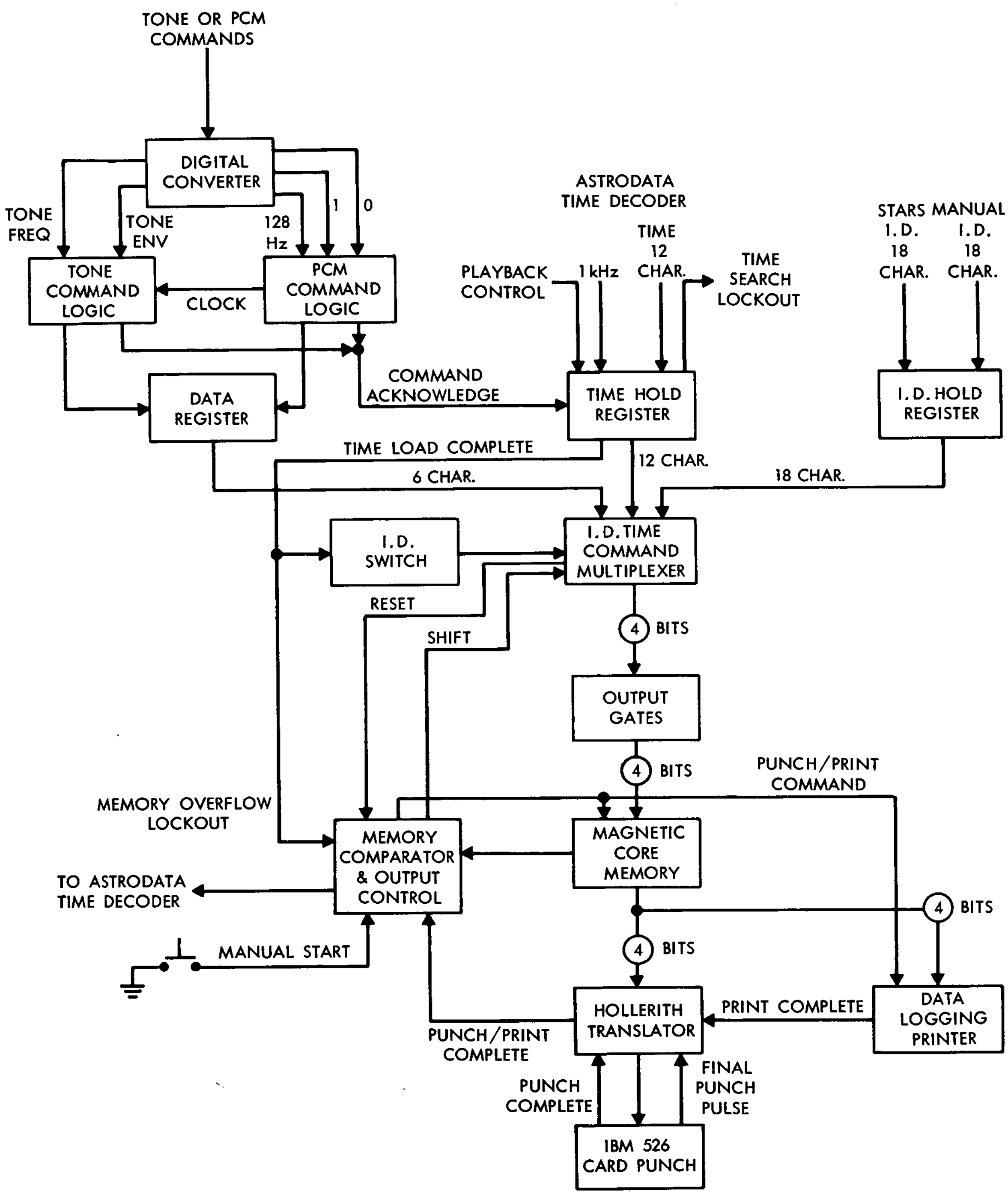



Figure 17—PCM and tone command processor system block diagram.

4. The three sets of data (consisting of 6 command characters, 12 time characters, and 18 ID characters) channeled through the multiplexer, which serially sequences them in a prescribed order.

5. An ID switch which adds versatility to the multiplexer and enables an ID word to be multiplexed with each command sequence, or only with the initial command sequence of a production run, or to lock out the ID word if it is not needed.

6. Output gates which pass 4-bit BCD characters from the command processing circuits to core storage.

## Output Cycle Logic Elements

An output cycle is started by depressing a manual engaging button which sends a signal to output control circuits. Once an output cycle commences, the following system elements become active, as described below (see lower portion of Figure 17):

1. Output gates which generate timing and control pulses and initiate unload cycles for each character read back out from the magnetic core memory.

2. The magnetic core memory holds 1024 characters. The unit contains control and clocking logic, to load and unload data, and circuits to provide sequential and random-access addressing capability. The unit can accept or retrieve information in 5 microseconds.

3. A memory comparator accumulates a count of the number of characters stored during command processing. This quantity is used during the output, and represents the terminal address for the block of stored information. When the last address in which data has been stored is reached by the memory unit, the comparator and the memory address register will contain the same address, that is, have a coincident count. Comparison logic recognizes the coincidence and terminates an output cycle. This circuitry ensures that only those characters loaded into storage will be punched or printed during an output.

4. A Hollerith Translator converts the BCD bit configuration of a character extracted from memory into the Hollerith code used by the card punch circuits to produce an appropriate character output. The translator reduces the 4-bit coding down to a single level to select a numeric character, or to two levels to punch an alphabetic character.

5. Summary (IBM 526) Card Punch – This peripheral device punches out the data held in memory onto 80-column tabulating cards. When a character is punched it is also printed above the punched column. The card punch can punch characters at a rate of 18 per second. At this rate the entire magnetic core memory is unloaded in approximately one minute.

6. Data Logging Printer – The printer is used as a secondary output device. It accepts the 4-bit BCD configuration from the magnetic core memory and prints the characters serially onto strip printing paper. The printer is utilized for testing the output circuits and for emergency purposes when the summary and punch cannot be used.

## PCM and Tone Command Logic

The PCM and tone commands may be transmitted intermittently with both recorded on the same magnetic tape track. The decoder must be able to recognize both types of commands at its input and separate them for processing. The two different processors are therefore connected together at the system input and isolated by bandpass filters. After filtering, the selected commands are passed through signal detection and shaping circuits, transformed into voltage levels and pulses suitable for digital logic, decoded, arranged in BCD character configurations for each command, and finally sent through output gates. Then the command is stored in an output register that is shared jointly by both the PCM and tone command processing circuits. The data from the output register is sent to multiplexing logic which stores the command word, along with time and identification words, in the magnetic core memory. Figure 18 shows the processor logic from the common input and traces it through the command processor logic up to the output register and to the output gates feeding the multiplexer. The bottom part of the figure shows the PCM command logic; the top part shows the tone command logic. These are described below, in this order.

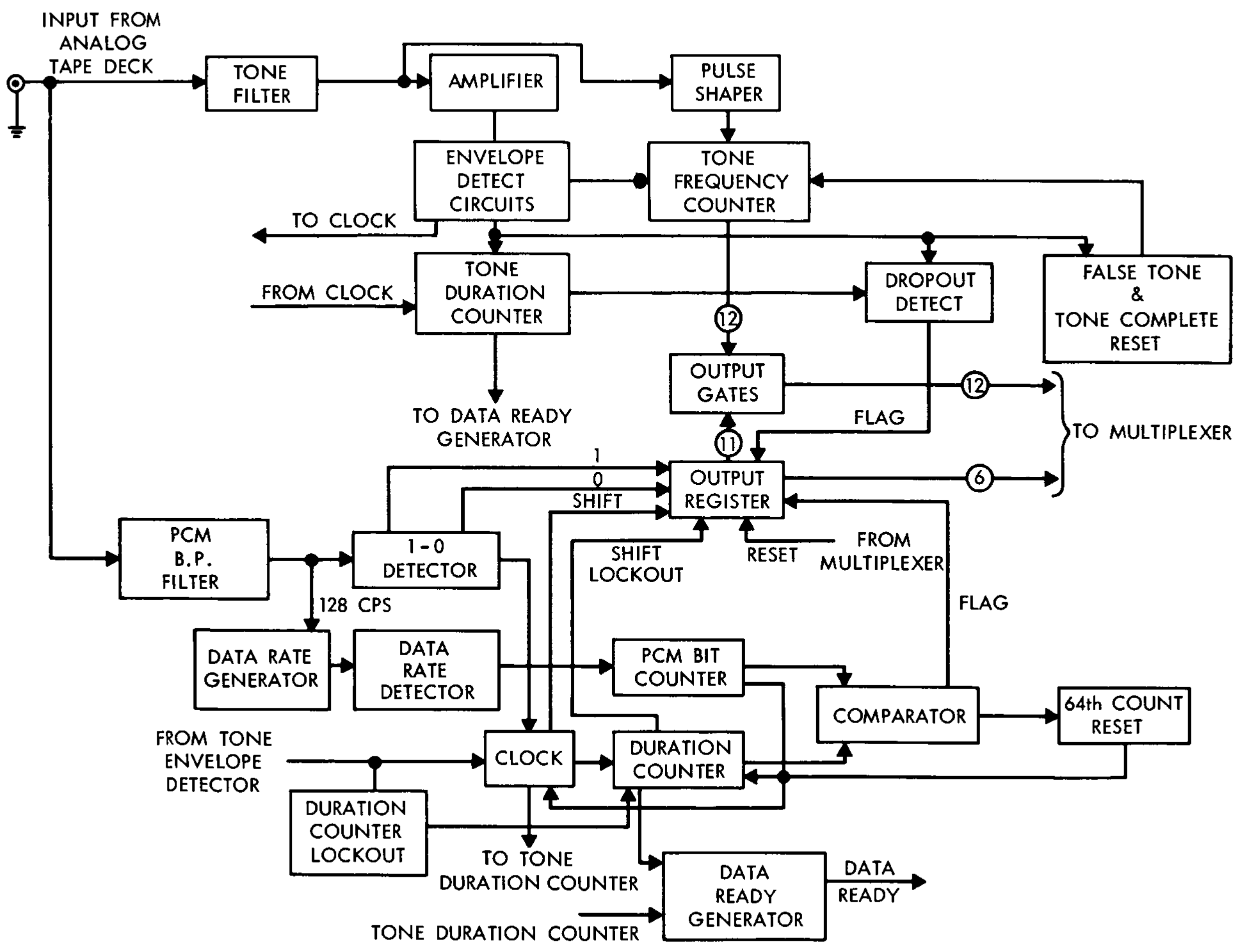


Figure 18—PCM and tone command processor logic block diagram.

## Functional Description of the PCM Command Logic

*Analog-to-Digital Converter*

The PCM command analog-to-digital signal converter circuits include subcircuits for the PCM bandpass filter, data rate generator, and binary "1-0" detector. (See Figure 18, bottom portion.) The design of these circuits is basically that of the analog-to-digital converter circuits of the OGO command decoder. Operational amplifiers were used for active elements in the filter portions, and incorporated in peak-following, baseline-resolution, pulse-shaping, and sawtooth-waveform-generating circuits. The improvements from the original system consisted of the introduction of network elements to provide greater noise immunity, better stability for voltage-level reference, and improved clock pulse generation. The task of the PCM digital converter is to detect 8.0-kHz and 8.6-kHz frequencies used for the OGO PCM commands. These frequencies represent binary one and binary zero, respectively. The converter also strips off the 128-Hz carrier, later used to produce the clock pulses to the digital logic circuits.

The PCM bandpass filter passes the 8.0- and 8.6-kHz frequencies, and rejects those outside of a narrow band encompassing them. The active filter is constructed with pi and T networks that apply strong attenuation to unwanted signals. The "1-0" detector separates the 8.0- and 8.6-kHz signals and directs them through noise-rejection and amplification circuits that eliminate any residue of the opposite frequency state. The output signal is presented to the digital logic circuits. The data rate generator extracts the 128-Hz carrier frequency from the command signal, refines and amplifies its peaks, and then develops a sawtooth waveform that is forwarded to the digital logic circuits for control functions.

*PCM Digital Logic*

The digital logic includes all the circuits used to decode and format the command data converted from analog representation, and consists of two subcircuits: the data rate detector and the PCM bit counter. The data rate detector receives the sawtooth waveform from the data rate generator. It examines the voltage threshold of the incoming signal and produces pulses at a 128-Hz rate. The detector will not produce a pulse if serious signal deterioration or dropout has occurred. The output of the detector is then fed into the PCM bit counter. The PCM bit counter increases each time a pulse is sent from the data rate detector. It normally counts up to 64 (the number of cycles of the 128 carrier frequency during a 1/2-second interval). The output of the counter is fed into a comparator gate to test for bit dropouts.

*PCM Logic Auxiliary Circuits*

The clock pulses for the system are produced by an oscillator that is turned on when the one-zero detector recognizes the first legitimate logical one bit in the incoming bit stream. The clock pulses are generated synchronous to the pulses from the data rate generator. The normal clock rate is 128 Hz, but the oscillator speeds up as required for 2 and 4 times playback reproduction speed. The clock is turned on when either PCM or tone commands are processed. Its purpose is to establish an incoming pulse that can be counted over the duration of the command signal. This offsets any dropout during a burst time and gives the system a phased flywheel to ensure that measurements will remain significant with respect to time. The clock also supplies the shift pulses to the storage register that accepts the serial bit stream of command data.

The duration counter is used to recognize and control the extraction and storage of the correct 16 bits from the 64-bit serial pulse train. It starts counting after the synchronized clock is turned on, and counts over the 16 bits that represent the address and execute portions of a command word. At the required bit time, the counter locks out clock pulses to the output storage register so that no more data bits can be shifted into it. When the final bit time (64th bit) of a PCM command is completed, the duration counter sends a reference strobe to another leg of a comparison network to test for bit rate dropout or distortion.

The duration counter lockout is needed since the clock output is used jointly by both PCM and tone command processors. Its function is to keep the duration counter from counting when tone commands are processed. This prevents an indicator, used to designate questionable PCM commands, from being turned on when no PCM commands are being processed.

The comparator is used to evaluate the counts held in the PCM bit counter and the duration counter at the end of a PCM command burst. It tests to see that all bit envelopes of an incoming command have been detected and properly developed. If signal fading or dropout has occurred, the PCM bit counter will not total up to 64 counts and will not match the duration counter. The comparator will place a flag bit in one preselected stage of the output storage register to signify that the command signal was distorted and that bit errors may be present.

The data-ready generator sends out a pulse called the "data ready" pulse after a command has been processed. This pulse occurs after the 64th (and last) pulse of the PCM command, and starts the loading cycle which places identification, time, and command data in the core memory.

The digital PCM command bits are sent to the output register and serially shifted in by the clock pulse. A flag bit is stored in one stage of the register if erroneous data are present. Shifting of the input bits terminates when the duration-counter decision circuits notify the system that the desired data have been shifted into the output register. One stage of this register is shared by the tone command processor when it decodes a command. This stage is used for an error flag when discrepancies appear during tone command processing.

The output gates are used jointly by both processor units, and pass the command data out to the multiplexer circuits of the system for separation and storage in the magnetic core memory unit.

The data configurations are different for the two types of command. The PCM command contains six octal characters of 18 bits (17 data bits, 1 flag bit), whereas the tone command contains four octal characters of 12 bits. Because of this, the upper two tone characters are multiplexed as zeroes. If an error has occurred, then one of the upper bits is used for a flag.

All control circuits of the PCM command processor are reset when a command processing cycle ends. The 64th count reset will reset all binary elements that perform a decision function.

The output storage register elements are reset separately, after data multiplexing has occurred, rather than by the 64th count reset. This is in order to prevent the data from being erased before storage takes place.

## Functional Description of the Tone Command Logic

The tone signal conversion circuits consist of the tone filter, the amplifier, and part of the envelope detection logic blocks shown in Figure 18 (top portion). The tone filter eliminates frequencies outside of the 1025- to 6177-Hz band assigned for tone commands. Two pi filters attenuate the undesired frequencies and forward the remaining signal to an active low-pass filter stage designed to reject a 800-Hz turnoff signal sent at the end of a tone command sequence. The output from this stage is a smoothed-out frequency burst; it is sent to pulse-shaping circuits in the digital logic. The signal also goes to a voltage amplifier, to increase the signal strength, and then to the initial stage of the envelope detect circuits, which follow the peaks of the frequency and develop a rough envelope during the incoming burst. This envelope goes to logic circuits in the envelope detect circuits, where squaring and signal refinement take place.

The tone digital logic blocks shown in Figure 18 consist of the envelope detection circuit, pulse shaper, tone frequency counter, tone duration counter, dropout detect circuits, resets, and the common output gates.

The pulse shaper takes the incoming 0.5-second frequency burst from the tone filter, squares the pulses within it, and adjusts the level of the signal to the voltage levels of the digital logic following it.

The envelope detection circuits, previously mentioned, include stages of both the analog-conversion and logical elements. The analog circuit is a peak-follower network that developed an unrefined envelope over the duration of the tone frequency burst. The digital portion shapes the envelope and level-shifts it so that it will be a voltage usable by other digital logic elements. The leading edge of the squared envelope is used to turn on the oscillator, which produces a 128-Hz clock pulse for both command processors. This clock is speeded up when the processing is run at 2 or 4 times normal speed. The envelope is used for turn-on and turn-off control of the tone command processor and is routed to the tone duration counter, the tone frequency counter, the dropout detector, and the reset circuits.

The pulses developed by the pulse shaper are fed to a gated input of the tone frequency counter. The output of the envelope detection circuits activates the gating circuit for the duration of a tone burst and allows the counter to assimilate a value equal to the number of pulses in the tone burst.

The incoming 128-Hz clock pulse advances the tone duration counter and accumulates a count of 64 over the 500-millisecond interval. The counter increases only while a tone-burst envelope is present. The output of the counter, signified by a set logic level, is used to verify that the tone burst lasts for its specified period.

The dropout detector accepts the output of the tone duration counter and tests it against the tone envelope voltage. If a comparison of agreement is made, nothing occurs, but if a count less than the required 64 is in the counter, the dropout detector will produce an error flag bit to indicate signal dropout or fading.

The false-tone and tone-complete reset circuit generates a reset pulse that clears all bistable components of the tone command processor. It is triggered at the end of a tone burst; so, if the burst ends prematurely and does not reestablish itself within certain correction tolerances, the system will be reset. At the end of a normal 500-millisecond tone burst, the system will be reset as expected.

The output gates as stated previously, are shared with the output stages of the PCM command processor output register. The flag bit placed in one bit of that register is passed out directly to the multiplexer along with the other bits sent through the output gates.

## VIII. ADVANCED COMMAND PROCESSOR CONSIDERATIONS

A highly flexible command processing system is being developed by the Information Processing Division of the Goddard Space Flight Center. The system is to be connected to a STARS, PHASE II system for automatic processing. The command processor will handle either PCM and tone, or tone and tone-digital command formats at processing speeds of 1/8th to 32 times speedup. The system will be computer-program-controlled and automatically adjusted to handle any command formats consistent with the prescribed GSFC command standards. It will read a decoded time word with every command, will provide the computer with command identification bits, and will flag signal dropouts and bit losses.

This system is elaborate in scope. It utilizes the best features of the previous systems where they are appropriate. It includes advanced techniques in both the analog and digital circuits needed to process at greater varying playback speeds. Design considerations have been directed toward the solution of the problems of resolving and decoding command data troubled by foreign analog signals on the same tape track and having amplitude and frequency distortion.

## IX. FUTURE COMMAND DECODING SYSTEMS

In order to handle the variety of command structures that can be arranged within the broad requirements of the GSFC command standards, a command processor that is universal in character must be developed.

All of the satellites that have been launched, and future proposed satellites, use either the tone, tone-digital, or PCM command formats by themselves or a combination of tone and tone-digital commands or of tone and PCM commands. The desired command processor should be able to receive and process all the command formats in any random sequence, provided that the command structure has been designated. This necessitates stringent design criteria in order to differentiate between common frequencies or timing conditions, particularly those of the PCM and tone-digital commands. Since there is no forseeable use for all three command formats with one satellite, a compromise can be made in design; an input can be made using either one of two selected formats.

This eliminates a good many of the special filters and digital logic circuits that would be needed to distinguish between the command formats if all three were used. Analog signal recording presents a major problem. Experience has shown that the command signal may be recorded at a voltage ±12 db or greater from the desired level. This necessitates a strong gain-control circuit with a rapid response. Adjustment can take care of much of this condition, but in a universal system automatic correction is necessary.

## X. CONCLUSIONS

A significant amount of knowledge has been gained in the area of command decoding since the program for producing the three command processors was initiated. Experience gained from use of the first and second systems either justified initial circuit design or led to improvements in them. A number of design techniques, based on assumptions of little known signal conditions, were reevaluated during the course of phasing the three systems into operation.

Close attention was paid to signal dropout; error-checking circuits were placed in the systems to indicate the presence of such occurrences. This condition would have been particularly harmful to the first PCM processor, which depended on a reconstructed bit-rate envelope to produce its clock pulses for control and data shifting. As noted, the PCM processor in the third command processing system had an internally triggered clock to provide insurance against data dropout. The processing of many commands has indicated that complete signal droput due to encoding and recording the commands should not happen. This is not to say that such an event never occurs, but it has not been found to occur often enough to require elaborate compensating check circuits. This has been true of tone and tone-digital commands as well as PCM commands.

The major problems have been presented in the recovery of analog signals. The recorded commands in a great many instances have suffered from wide amplitude variations at the input to the system. The processing problems expected to occur with a complete dropout are also present with extreme fading or flareups. When signals cannot be recovered, the check and flagging circuits are needed to indicate that there is a question as to the quality of the command signals. Amplitude variation is by far the most serious processing problem. A weak signal at the input may not be recovered, because it cannot be pulled out of the noise that accompanies it. On the other hand, a signal recorded at an amplitude higher than the specified upper limit of the analog-to-digital converter will often saturate the circuits and cause internal timing problems as well as incorrect data.

Signal distortion has appeared on many recorded commands. The PCM and tone commands have been processed for active satellites so that, for these, a substantial knowledge of signal conditions has been observed. These conditions had been largely anticipated, and circuits designed to compensate for them.

The commands were observed to vary at low-frequency oscillations about the center reference voltage; also, level changes of the baseline voltage occasionally appeared on recorded tapes. The conditions did not affect the processor response unless the shifts were too extreme.

In any command decoding scheme it is necessary to develop circuits that can both respond and accurately assess the command signals when they are transmitted. The infrequent and random pattern of command encoding for transmission of instructions to a satellite produces signals that deviate markedly from one command to another. Overshoot or slow response may occur. The analog detection circuits in the processor were developed to distinguish between correct command frequencies and noise bursts; the digital logic identified noise bursts of the frequencies used in the command format and controlled system response to them.

The techniques used at the interface of the analog-to-digital circuits were durational counting for the tone commands, frequency separation, and envelope generation for the PCM commands, and pulse integration and level detection for the tone-digital commands. All depended on selective filters at the input for correct frequency isolation, and decision-making circuits that observed the commands with respect to their programmed lengths, in order to guarantee accurate data. The duration of each command burst is not as critical a factor as was initially supposed. Sampling techniques to determine the frequencies can just as easily be used as the types of circuits described and are more desirable for systems reproducing the data at higher playback speeds.

In retrospect, it can be said that the systems amply satisfy the purpose for which they were designed. They accurately process commands with wide variations in amplitude and low signal-to-noise ratios.

Goddard Space Flight Center
National Aeronautics and Space Administration
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NASA-Langley, 1967 —— 31